GAS TURBINE AND JET ENGINE FUELS

PROGRESS REPORT NO. 3

NAVY BUWEP CONTRACT NO. (W) 61-0590-D

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PHILLIPS PETROLEUM COMPANY

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by

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SUMMARY

The third bimonthly period under Contract No(w)61-0590-d has been spent continuing the study of the effects of fuel sulfur and ingested sea water on jet engine "hot section" durability. Efforts to determine the reason for the previously observed higher corrosion rates obtained during operation with ingested natural Gulf sea water as compared to synthetic sea water have shown that:

1. Copper and/or nickel contamination of the natural Gulf sea water was responsible for its greater corrosiveness.

2. Artificial contamination of the test fuel with copper failed to cause any increase in flame tube metal loss as compared to results with the neat fuel, indicating that the copper effect is linked to its inclusion in the sea water.

3. In the absence of copper and/or nickel, it would continue to appear that under the conditions of these tests ingested sea water had no adverse effect on flame tube durability.

Additionally, efforts have been initiated toward evaluation of the effect of fuel sulfur and sea water on turbine inlet guide vanes. Results obtained to date have shown the following:

1. Metal loss tests using type 304 stainless steel simulated guide vanes showed no sensitivity to 1 per cent fuel sulfur and low metal losses at 1350 F exhaust gas temperature.

2. At 1650 F exhaust gas temperature the metal loss with sulfur-free fuel rose 590 per cent and sulfur was found to be very detrimental, as shown by a 50 per cent increase in metal loss over results with the sulfur-free fuel at this temperature.

PHILLIPS PETROLEUM COMPANY

BARTLESVILLE, OKLAHOMA

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I. INTRODUCTION

The third bimonthly period under Navy Contract NO(w)61-0590-d has been spent continuing the study of the effects of sulfur in jet fuels and ingested sea water on the durability of jet engine "hot section" components. Efforts during this period have included attempts to determine the reason for higher flame tube corrosion rates observed during operation with ingested natural Gulf sea water as compared to synthetic sea water, reported in Progress Report No. 1. Additionally, efforts have been initiated toward the development of a suitable test method for the evaluation of the effect of fuel sulfur and sea water on simulated turbine inlet guide vane durability. This report will discuss the results of preliminary experiments using "cart-wheel" shaped simulated guide vanes during operation with a nearly sulfur-free fuel and with this same fuel contaminated with 1 per cent sulfur.

II. TEST PROGRAM

The apparatus used in this investigation was the Phillips 2-inch Research Combustor which has been described in complete detail in previous reports (1). Briefly, this is a 2-inch diameter axial flow combustor embodying the principal features of modern jet engine combustion systems. Air is supplied to this combustor from a compression and heating plant described in (1), while fuel is supplied to the swirl type nozzle by nitrogen pressurization. The design of the combustor is such as to allow ready removal of flame tubes for inspection, weighing, etc.

The flame tube metal loss test procedure consists of cleaning and weighing a new flame tube before each test, installing it in the combustor test assembly and measuring the weight loss (by difference) following each of three consecutive one-hour test periods.

Test conditions employed were identical to those used for previous investigations of the effect of sulfur and sea water on flame tube durability which have been reported on in (2). Combustor pressure was held at 350 in. Hg. abs., inlet air temperature at 700 F and inlet reference velocity at 100 fps, providing a severity level which is reasonably realistic for high compressor ratio turbojets operating at relatively low altitudes. For the flame tube tests the fuel-air ratio was held at 0.010 lb. fuel per lb. of air.

For the preliminary investigations of the effect of sulfur on turbine inlet guide vanes no change was made to the combustor section itself. For this work the only change in apparatus was simply to add a six-inch spoolpiece just downstream from the combustor and to cut a suitable holder cavity into its mating flange for the simulated turbine inlet guide vane pieces shown in Figure 1, placing these pieces in a position comparable to that of the real blading in an actual engine. The design of these test pieces was based not so much upon a close simulation of configuration as upon simplicity and ease of fabrication. The operating conditions employed for these tests were the same as outlined above for the flame tube durability tests with the exception that data were obtained at a fuel-air ratio of 0.015 lb fuel per lb of air as well as at 0.010 and weight losses were measured following each of three consecutive two-hour test periods, rather than one-hour periods. This increased time was found to be necessary in order to realize weight losses high enough to be accurately measurable. During this reporting period, in which the major objective was to establish a workable test method and test piece design, data have been obtained using only type 304 stainless steel specimens.

Since previous investigations (3) had shown sulfur compound type to be unimportant as compared to gross sulfur concentration, it was decided to continue using the single compound ditertiary butyl disulfide, which is relatively inexpensive and readily available. In order to exaggerate the sulfur severity for testing purposes it was decided to employ this compound at sufficient concentration to realize 2.5 times the jet fuel specification sulfur limit of 0.4 per cent, or, in other words, 1.0 per cent sulfur, since considerable previous data were available at this concentration.

The base fuel selected for this work was, as in the case of previous investigations, a JP-5 type isoparaffinic alkylate containing 0.005 per cent or less sulfur. Typical properties of this base fuel have been shown in (2).

III. DISCUSSION OF EXPERIMENTAL RESULTS

A. Effect of Sea Water on Flame Tube Metal Loss

It should be recalled from Progress Report No. 1 that the injection of synthetic sea water (ASTM D665-60) into the Phillips 2-inch Research Combustor at rates 2.5 and 5000 times that indicated in the literature (4) as representative of the concentration of airborne sea water vapor at an altitude of 50 feet over the ocean surface caused no significant change in flame tube metal loss values from those observed for operation on a synthetic 1 per cent sulfur fuel without sea water injection. However, when natural Gulf sea water was injected increases in flame tube metal loss were observed and their magnitude was nearly the same without sulfur in the fuel as with sulfur, indicating not only a difference between the synthetic and natural Gulf sea waters but also that the corrosive effects of sulfur and this particular sample of natural sea water were not synergistic but independent.

During this third bimonthly period an effort has been made to determine why there should have been a difference in corrosiveness between the synthetic and natural sea water samples used. Toward this end spectrographic analyses of both sea water samples were carried out and these analyses showed comparable types and concentrations of major metal constituents. However, the natural Gulf sea water showed trace amounts (30 ppm and 55 ppm) of copper and nickel - metals not contained in the synthetic sea water. The Gulf sea water had been stored in a stainless steel drum for 3 or 4 years and it would seem possible that it could have picked up these trace contaminants from the drum material.

In an effort to reproduce the effect of the copper and nickel implied by the results of the tests on natural sea water, a sample of synthetic sea water was contaminated with 100 ppm of cupric chloride and 100 ppm of nickel chloride. The results of the flame tube metal loss test run with sulfur-free fuel and this copper-nickel contaminated synthetic sea water (injected at the same rate as in previous tests - 3.1 per cent of fuel input) are shown in Figure 2. Although there is some deviation of this curve from the corresponding curve for natural sea water, the terminal value is about the same, confirming that copper and/or nickel in sea water does tend to accelerate the corrosion of flame tubes.

Although nickel was added as a contaminant in this test, its presence in the sea water is considered to be of only little consequence since it is present in copious quantities in both the combustor and fuel system of the 2-inch combustor (and full-scale engine, as well). Rather, it would seem that the test results point to copper as the real corrosion accelerator. Bearing this in mind, and with the intent of determining the effect of copper independently of sea water, a test was run under the same conditions as those previously described, eliminating the sea water entirely and adding copper (as cupric oleate) directly to the fuel at a concentration in the fuel (3 ppm) corresponding to the input of copper resulting from the injection of the synthetic sea water contaminated with 100 ppm copper. The results of this test are also shown in Figure 2 and they indicate that copper added to the combustor in this way has no effect on flame tube durability. This suggests that the copper acts in some way to alter the corrosiveness of the sea water while remaining non-corrosive in itself. At any rate, these results do tend to confirm that the previously observed higher corrosion rates obtained with natural Gulf sea water are attributable to the presence of copper. Of significance, of course, is the implication that, in the absence of copper, sea water would have no effect on flame tube durability under these operating conditions. This is not to say that this would be true under more severe conditions and for this reason it is intended in the future to repeat these tests at a higher fuel-air ratio.

B. Effect of Operating Conditions and Fuel Sulfur on Simulated Turbine Inlet Guide Vanes

The results of the simulated turbine inlet guide vane durability tests conducted thus far are shown in Table I. Since these preliminary efforts were intended primarily to establish a suitable test method and to determine the usefulness of the simulated guide vane design shown in Figure 1, only type 304 stainless steel vanes have been used. Six-hour tests have been conducted using a sulfur-free base fuel with and without contamination with 1 per cent sulfur as ditertiary butyl disulfide at F/A ratios of 0.010 (resulting in exhaust gas temperature of approximately 1350 F) and 0.015 (exhaust gas temperature of approximately 1650 F). These data, plotted in Figure 3 as accumulated vane metal loss versus test time, show that at the lower fuel-air ratio not only were metal losses low but the sulfur added to the fuel seemed to have no effect, indicating that sulfur corrosion of turbine blading may not be a problem under these conditions (simulated low altitude cruise). However, as test conditions were made more severe by increasing the fuel-air ratio to 0.015 (simulating low altitude take-off) metal losses increased markedly and the effect of sulfur was observed as a 50 per cent increase in six-hour metal loss as compared to that obtained with the sulfur-free base fuel. Although the sulfur effect here became very significant, the effect of increasing exhaust gas temperature from approximately 1350 F to approximately 1650 F resulted in a 590 per cent increase in vane metal loss (based on tests with the sulfur free fuel), showing that guide vane durability is sharply temperature dependent in this range, with or without sulfur.

On the basis of the preliminary tests described above, it appears that the design of the corrosion specimen and the method of placement and operation are workable and it is planned to continue with this arrangement.

IV. CONCLUSIONS

Two-inch combustor metal loss tests and spectrographic analyses conducted to determine the reason for previously-reported greater corrosion of flame tubes during operation with ingested natural Gulf sea water as opposed to synthetic sea water have shown the following:

1. Spectrographic analyses of the synthetic and natural Gulf sea water samples showed that the only significant difference was the presence of trace amounts of copper and nickel in the natural sea water.

2. Flame tube metal loss tests conducted with ingested synthetic sea water artificially contaminated with copper and nickel yielded results essentially duplicating those obtained for tests with the natural Gulf sea water, confirming that these contaminants were responsible for the differences observed between synthetic and natural Gulf sea water.

3. Artificial contamination of the test fuel with copper failed to cause any increase in flame tube metal loss above the value observed for the uncontaminated fuel, indicating that the copper effect is one linked to its inclusion in sea water.

4. Under the conditions existing in the combustor during these tests it would appear that, in the absence of copper and nickel, sea water had no adverse effect on flame tube durability when ingested at a rate 5000 times that indicated by the literature to be typical for low level flight over the ocean.

Initiation of tests toward development of suitable corrosion specimens and test technique for evaluation of the effect of sulfur, sea water and other contaminants on turbine inlet guide vane durability have shown the following:

1. Cart-wheel shaped corrosion specimens fabricated from 16 gage sheet stock and placed 6 inches downstream from the Phillips 2-inch Research Combustor were found to offer a workable means for simulating turbine inlet guide vanes for corrosion test purposes.

2. Metal loss tests conducted using type 304 stainless steel simulated turbine inlet guide vanes showed no sensitivity to the presence of 1 per cent fuel sulfur and very low metal losses under operating conditions resulting in an exhaust gas temperature of 1350 F. However, upon increasing the exhaust gas temperature to 1650 F by increasing fuel-air ratio from 0.010 to 0.015 the metal loss with sulfur-free fuel rose 590 per cent. At the higher F/A ratio the detrimental effect of sulfur was observed as a 50 per cent increase in metal loss as compared to that obtained with the sulfur-free fuel.

V. OUTLINE OF PROJECTED WORK

It is intended to investigate further the effect of sea salts in combination with fuel sulfur on flame tube durability under higher temperature conditions during the fourth bimonthly period under Navy Contract NO(w)61-0590-d. Greatest emphasis, however, will be placed on the effect of these contaminants on turbine inlet guide vanes at higher exhaust gas temperatures, using various practical turbine blading alloys.

REFERENCES

1. Fromm, E. H.; "Design and Calibration of Phillips Jet Fuel Testing Facilities", Phillips Research Division Report 1252-55R, December, 1955.

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3. Kittredge, G. D. and Streets, W. L.; "Gas Turbine and Jet Engine Fuels", Summary Report for Navy Contract NOas60-6009-c, Phillips Research Division Report 2760-60R, January, 1961.

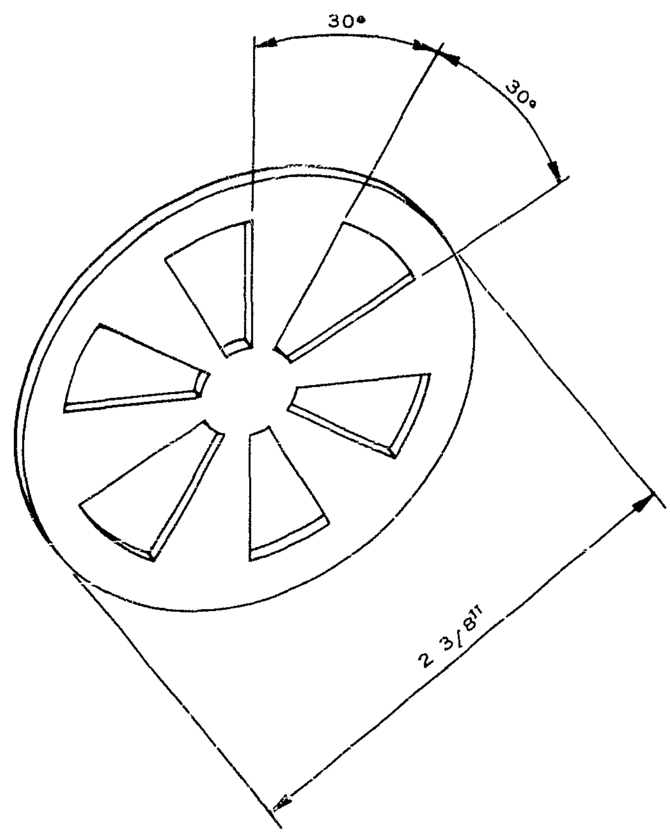
4. Woodstock, Alfred H. and Gifford, Mary M.; "Sampling Atmospheric Sea-Salt Nuclei Over the Ocean", Journal of Marine Research, Volume VIII, 1949.

TABLE I

SIMULATED TURBINE INLET GUIDE VANE DURABILITY IN PHILLIPS 2-INCH RESEARCH COMBUSTOR

Combustor Operating Conditions: P = 350 in. Hg abs.; V = 100 ft./sec.; IAT = 700F

Vane Metal Type	Test Fuel Description	Fuel/Air Ratio	Time, hrs.	Accumulated Metal Loss, mg.	Exhaust Gas Temp., °F
304SS	JP-5 Type Alkylate (PJ61-8-B1)	0.010	2	28.5	1346
		0.010	4	39.5	1382
		0.010	6	68.0	1352
304SS	JP-5 Type Alkylate (BJ61-8-B1)	0.010	2	6.8	1314
		0.010	4	54.8	1326
		0.010	6	66.5	1362
304SS	JP-5 Type Alkylate (BJ61-8-B1) plus 1% Sulfur as Ditertiary Butyl Disulfide	0.010	2	18.9	1346
		0.010	4	32.3	1340
		0.010	6	54.2	1306
304SS	JP-5 Type Alkylate (BJ61-8-B1)	0.015	2	89.0	1660
		0.015	4	242.0	1666
		0.015	6	464.0	1605
304SS	JP-5 Type Alkylate (BJ61-8-B1) plus 1% Sulfur as Ditertiary Butyl Disulfide	0.015	2	121.0	1592
		0.015	4	399.0	1632
		0.015	6	691.0	1625



MATERIAL: VARIOUS TYPES OF TURBINE
BLADING ALLOYS (16 GA. SHEET)

FIGURE 1
SIMULATED TURBINE INLET GUIDE VANE INSERT FOR MEASUREMENT
OF DOWNSTREAM METAL LOSSES IN PHILLIPS 2- INCH COMBUSTOR

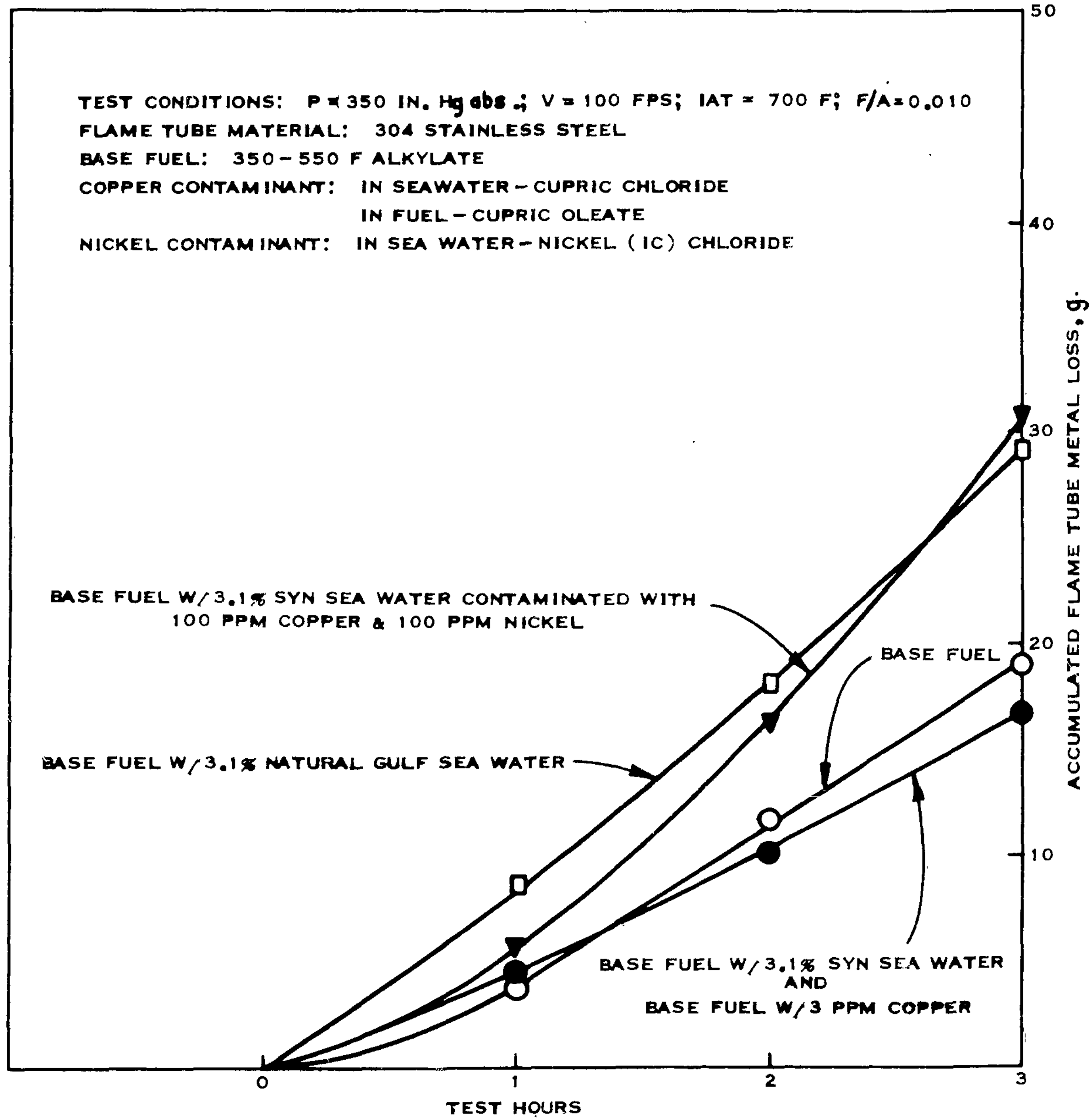


FIGURE 2
EVALUATION OF THE EFFECT OF COPPER AND NICKEL IN SEA WATER AND COPPER IN FUEL ON THE DURABILITY OF TYPE 304 STAINLESS STEEL FLAME TUBES

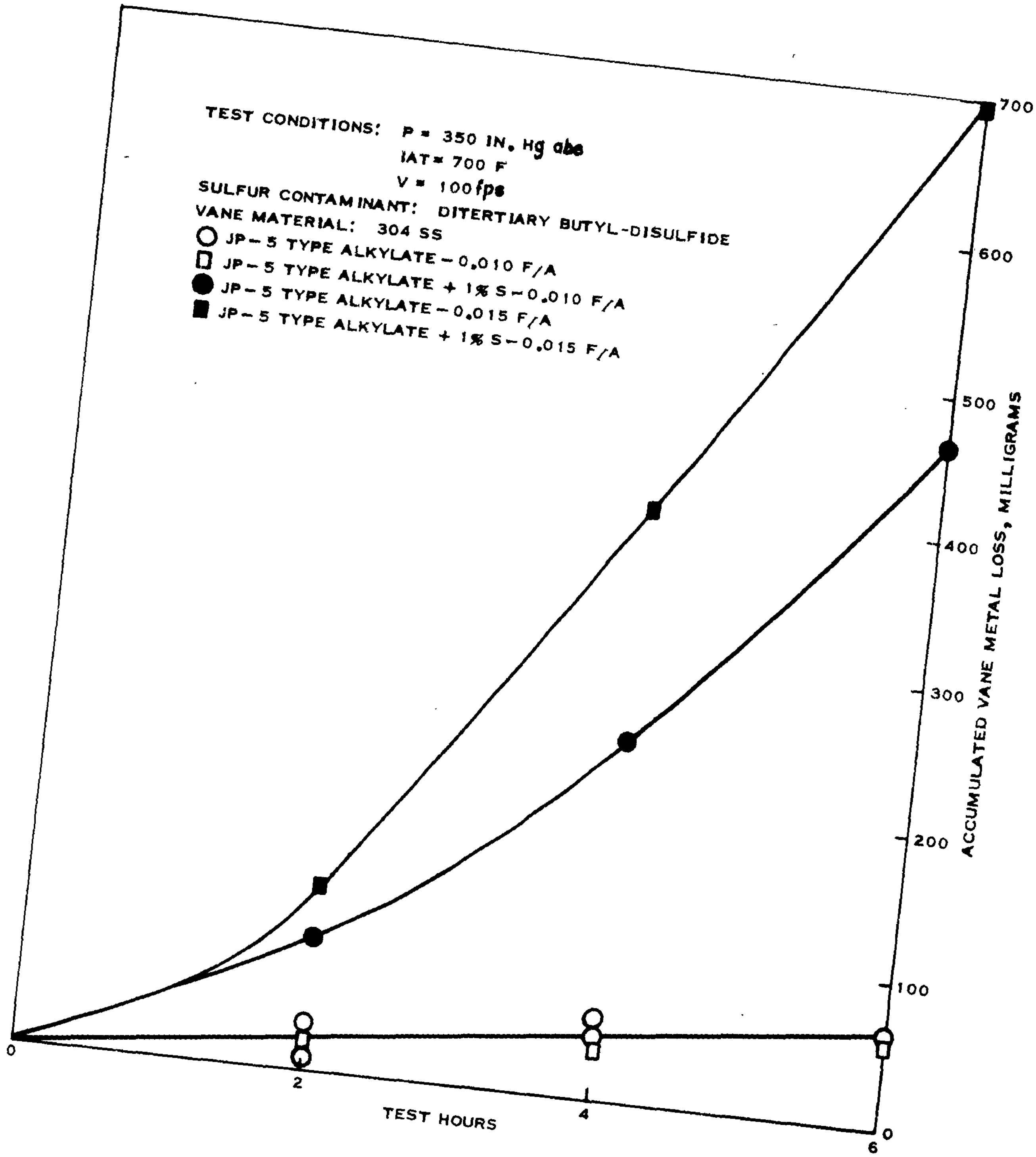


FIGURE 3

EFFECT OF FUEL SULFUR CONTAMINATION AND FUEL/AIR RATIO ON THE RATE OF METAL LOSS FROM SIMULATED TURBINE INLET GUIDE VANES IN THE PHILLIPS 2- INCH RESEARCH COMBUSTOR